

Correlation of the Hubble Space Telescope (HST) Space Telescope Imaging Spectrometer (STIS) On-Orbit Data with Pre-launch Predictions and Ground Contamination Controls

The Hubble Space Telescope (HST) Space Telescope Imaging Spectrometer (STIS) was deployed on-orbit in February 1997. The contamination program for STIS was stringently controlled as the five-year end-of-life deposition was set at 15A per optical element. Contamination was controlled through materials selection, extensive bakeouts, cleaning techniques, and environmental controls. In addition to ground contamination controls, on-orbit contamination controls were implemented for both the HST servicing activities and early post-servicing checkout. This paper will discuss the extensive contamination control program and the correlation of the STIS on-orbit data with pre-launch predictions.

CORRELATION OF THE HUBBLE SPACE TELESCOPE (HST) SPACE TELESCOPE IMAGING SPECTROGRAPH (STIS) ON-ORBIT DATA WITH PRE-LAUNCH PREDICTIONS AND GROUND CONTAMINATION CONTROLS

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ABSTRACT

The Hubble Space Telescope (HST) Space Telescope Imaging Spectrograph (STIS) was deployed on-orbit in February 1997. The contamination program for STIS was stringently controlled as the five-year end-of-life deposition was set at $15\text{\AA}$ per optical element. Contamination was controlled through materials selection, extensive vacuum outgassing certifications, cleaning techniques, and environmental controls. In addition to ground contamination controls, on-orbit contamination controls were implemented for both the HST servicing mission activities and early post-servicing mission checkout. The extensive contamination control program will be discussed and the STIS on-orbit data will be correlated with the pre-launch analytical predictions.

1. INTRODUCTION

The Space Telescope Imaging Spectrograph (STIS) is one of the Hubble Space Telescope (HST) second-generation instruments. It was installed into the telescope during the HST second servicing mission, STS-82, in February 1997. Extensive contamination controls were implemented for both the servicing mission (SM) hardware and the STIS instrument itself [1-3]. The on-orbit data has been analyzed to determine the sensitivity losses of the instrument so that science observations can be corrected for these losses. The STIS contamination control program, the pre-launch contamination modeling predictions and the on-orbit data will be discussed.

2. HUBBLE SPACE TELESCOPE

The HST was designed to be periodically serviced on-orbit during its 20-year mission. The HST science observations are accomplished through five science instruments (four axial and one radial) and three Fine Guidance Sensors (FGS). To-date, the HST has had four successful servicing missions occurring approximately every 2-3 years (see Table 1), during which critical systems and science capabilities have been upgraded during extra-vehicular activities (EVAs) or "space walks". These activities present an inherent risk to the cleanliness of the telescope, as

will be discussed later in this paper. However, a comprehensive contamination control program addressing the Orbiter, the Astronauts, and the carrier hardware, was developed and implemented for each of the servicing missions. This effort has been extremely successful and to-date, no on-orbit contamination events have been reported.

Table 1. HST Servicing Missions

<u>Mission</u>	<u>Designation</u>	<u>Date</u>
Deploy	STS-31	April 1990
SM1	STS-61	December 1993
SM2	STS-82	February 1997
SM3A	STS-103	December 1999
SM3B	STS-109	March 2002

3. SPACE TELESCOPE IMAGING SPECTROGRAPH

3.1 Instrument Design

The STIS instrument (shown in Figure 1) is a multi-element spectrograph with a complex set of optical systems and subsystems and is one of the HST's five scientific instruments that form part of the Focal Plane Assembly. The STIS replaced a first-generation instrument. The design of the spectrograph was limited by the envelope previously occupied by the Goddard High Resolution Spectrometer (GHRS). The 825 lb (374 kg) spectrograph is roughly the size of a telephone booth - 7 x 3 x 3 ft (2.2 x 0.9 x 0.9 m). The STIS instrument incorporated the aberration correcting optics into its design, which added two additional optics to the system. The STIS was designed to replace many of the basic capabilities of the GHRS, as well as enhancing those qualities with a broader wavelength range (1150 to 10000 Angstroms) and two-dimensional capability. It also provides the HST operational support during target acquisition.

3.2 Instrument Contamination Requirements

The overall mission derived contamination requirements was: *less than 9% reflectance degradation per optical element at end-of-life (defined as 5 years on-orbit)*. This further translated into a deposition thickness of 15Å per optical element (assuming "standard" non-silicone based materials). The extensive STIS contamination control program was designed to meet these stringent on-orbit optical requirements.

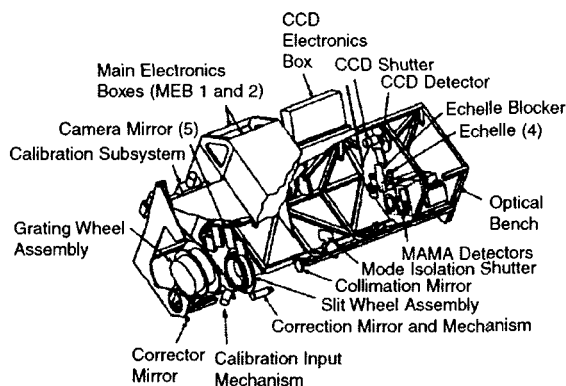


Figure 1. STIS Instrument Design

3.3 Instrument Contamination Control Program

The basis of the STIS contamination control program centers on the known extremely critical sensitivity of ultraviolet (UV) instruments to even low levels of contamination (current on-orbit requirements state a one monolayer limit). As a result, there has been a comprehensive contamination engineering effort performed for the STIS by GSFC, Ball Aerospace (instrument manufacturer), and all supporting contractor organizations.

The main contamination engineering efforts performed for STIS include the following [6-8]:

- The instrument design provided some isolation of the contamination sensitive optical elements from known contamination sources (e.g. electronics boxes).
- Non-metallic materials were limited and were selected based on low outgassing requirements. Large amounts of low-outgassing materials (such as Braycoat 601) were pre-processed prior to use to further reduce on-orbit outgassing.
- A substantial amount of contamination control planning was accomplished for the STIS, including development of detailed

contamination control plans, handling procedures, personnel procedures, etc.

- A full-scale optical monitoring program was implemented to measure the degradation of the UV performance of the optical elements during the spectrograph's integration and subsequent environmental testing and calibration. The instrument was monitored during Servicing Mission Integration and Test activities at the Goddard Space Flight Center (GSFC) and the Kennedy Space Center (KSC) launch site facilities, as well as during the actual servicing mission activities.
- All personnel involved with the STIS instrument at various contractor sites were trained and educated on the extreme contamination sensitivity of the instrument.
- A full-scale extensive outgassing certification (vacuum bakeout) program, beginning at the parts level and ending with the full-up integrated instrument, was implemented for the STIS instrument.
- Detailed contamination modeling analyses were performed for the STIS mission to determine the expected deposition levels on critical surfaces, at various points in the mission, and to identify possible major threats to instrument performance success.
- Detailed laboratory simulations and testing were performed on the STIS components to determine the effects of UV radiation on expected contaminant deposition and the subsequent effect on instrument performance.
- Detailed contamination controls were developed for on-orbit servicing mission activities. The controls were implemented for the spectrograph's installation into the HST and during additional servicing mission activities during subsequent missions (STS-103 in December 1999 and STS-109 in February 2002). Similar contamination controls will be implemented for the next SM, planned for mid-2004.
- Detailed contamination procedures were developed for on-orbit operations based on previously returned HST science instruments [8]. This included planning for a period during the HST operations verification, just after the servicing missions, when STIS remained shuttered to minimize exposure to UV sources (Earth) during the telescope's highest molecular contamination environment. Subsequent

exposures of the STIS optics to bright objects were also limited during normal HST operation.

4. PRE-LAUNCH CONTAMINATION MODELING PREDICTIONS

The STIS instrument was extensively modeled to predict on-orbit depositions from the instrument itself, other instruments in the HST, and to evaluate potential damaging effects due to exposure to UV sources. Actual component or system level outgassing data was used in the models. Where no data was available, data was used from the GSFC outgassing database. During the STIS instrument servicing mission, there were also two new instruments installed into the HST Aft Shroud, the Near Infrared Camera Multi Object Spectrometer (NICMOS) and Fine Guidance Sensor (FGS). All other instruments on the HST had been on-orbit from the initial HST deploy mission and SM1 (3-7 years). Thus the molecular contamination contributions from the existing instrument complement were considered to be negligible. Due to the sensitivity of the NICMOS instrument, it underwent a similar component processing program as the STIS (vacuum bakeouts, cleaning techniques, etc. as appropriate) and was also considered to be a negligible outgassing source to the STIS during on-orbit operations.

Previous experience with the HST, based on post-mission analyses of the Wide Field and Planetary Camera I (WFPCI), had indicated that the Fine Guidance Sensors (FGSs) were the most likely source of the on-orbit outgassing contamination [8]. Although the post-mission analyses indicated a significant deposition on the WFPCI pick-off mirror (approximately 450 Angstroms), due to the optical signature of the deposition, very little if any on-orbit degradation of the WFPCI science measurements occurred. The WFPCI primary science wavelengths were greater than 1740 Å. The data showed a significant reflectance loss below 1800 Å – with a total reflectance loss of approximately 98% at 1216 Å [8]. Although not significant for the WFPCI, for STIS similar contamination levels would have been catastrophic to the planned science observations.

As a result of these analyses and the STIS instrument contamination requirements, the design and replacement requirements for the FGS (1R) included significant pre-mission processing (including extensive vacuum bakeouts) to reduce its on-orbit outgassing [9]. The measured outgassing rate of the FGS (1R) was incorporated into an existing HST contamination model and the flux rate to the STIS

instrument was calculated. Estimated outgassing rates for the on-orbit FGSs were also included in the analyses. These “input fluxes” were incorporated into the STIS contamination model. Two “sticking” coefficients were used to account for both thermal accommodation and UV accommodation. Based on the amount of time that the HST views bright objects (Earth), the UV accommodation was further reduced by 22 percent (average values based on on-orbit operations data). The UV accommodation assumed that material deposited on a surface that was exposed to UV would be “affixed” to the surface. This meant that material that would not be necessarily thermally accommodated to the surface would in fact remain if exposed to UV.

The STIS end-of-life depositions were calculated from all sources for 24 contamination critical surfaces. These results are shown in Table 2 [10]. By constraining the outgassing levels from the FGSs and the STIS instrument itself to the overall HST outgassing environment (by performing extensive pre-mission vacuum bakeouts), analytical modeling results yielded predicted levels of deposition ranging from 2-5 Angstroms. When the UV accommodation factor was also added (shown in the table as “Total Deposition”) the predicted levels ranged from just over 9 Angstroms to over 26 Angstroms. These “Total Deposition” predictions indicated that STIS would exceed its on-orbit contamination requirements and impact planned science observations. Based on these modeling results, an on-orbit operations scheme was developed that allowed STIS to close its shutter during bright object viewing (Earth passes). The STIS post-servicing mission on-orbit checkout was also delayed to the end of the HST on-orbit checkout period. This scheme allowed the majority of contamination present inside the HST due to servicing mission activities to dissipate. Thus the predicted deposition levels were reduced to those shown as “Outgassing Depositions” (thermal accommodation only). These deposition amounts were well within the on-orbit contamination limits.

Table 2. STIS Predicted On-Orbit Deposition

<u>Critical Surface</u>	<u>Outgassing Deposition, Å</u>	<u>Total Deposition, Å</u>
MSM Optics Ring	4.20	16.84
CCD Window	2.77	10.57
MAMA 1, Window	2.56	10.07
MAMA 2, Window	2.46	9.62
Corrector 1 (CM1)	4.67	26.37
Cal. Insert Mech. Mirror	3.70	15.81
SWF – A (Fore)	3.49	14.76
SWF – A (Aft)	3.18	13.4
SWF – B (Fore)	3.49	14.68
SWF – B (Aft)	3.28	13.60
MAMA 1, OM (K1B)	3.38	13.07
MAMA 2, OM (K2B)	3.28	12.97
MAMA 1, OM (K1A)	3.08	12.66
MAMA 2, OM (K2A)	3.08	12.56
CCD, OP (K3)	2.86	10.86
Collimator Optics (CLM)	2.67	10.78
CCD, FFM (M3)	2.76	10.45
MAMA 1, FFM (M1)	2.87	11.08
MAMA 2, FFM (M2)	2.86	10.86
Echelle Grating (EG13)	3.17	11.60
Echelle Grating (EG14)	3.17	11.50
Echelle Grating (EG23)	3.17	11.60
Echelle Grating (EG24)	3.17	11.50
<u>Corrector Mirror (CM2)</u>	4.33	21.19
SWF – Slit Wheel Filter		
OM – Off-axis Mirror		
OP – Off-axis Parabola		
FFM – (Fold Flat Mirror)		

5. STIS ON-ORBIT DATA

Periodic measurements of the spectrograph's sensitivity have been made during the past six years [11-14]. These studies have coincided with observations during the science cycles after servicing mission activities were concluded. During the period that the STIS has been operational, there have been 3 servicing missions – SM2, SM3A, and SM3B. During these servicing missions, critical HST systems were upgraded and replaced. The servicing missions utilize the Space Transportation System (Shuttle) to lift replacement hardware (instruments,

gyros, computer, FGS, etc.) and support equipment into orbit, capture, stow and release the HST, and provide a platform to service the HST. Approximately 5-6 EVAs are planned for each SM. Special precautions, captured in the servicing mission unique flight rules, govern both the Shuttle and astronaut activities during these EVAs. Additional precautions are taken when the new and replaced instruments are exchanged and the HST Focal Plane Assembly is open to the Shuttle environment.

During the SM2, the STIS, NICMOS, and FGS (1R) were installed into the telescope. The HST Aft Shroud (the Focal Plane area behind the primary mirror where the instruments are located) was open to the Shuttle environment for approximately 11 hours.

During the SM3A, 3 gyro assemblies and an FGS (2R) were installed into the telescope. The HST Aft Shroud was open to the Shuttle environment for approximately 10 hours.

During the SM3B, the Advanced Camera for Surveys (ACS) instrument and cooling system hardware were installed. The HST Aft Shroud was open to the Shuttle environment for approximately 8 hours.

5.1 STIS Turn-on (Post SM2)

The change in the STIS CCD sensitivities (average) was reported at less than 1% per year [11]. No significant losses of sensitivity due to contamination or any other cause were observed during this post-SM2 science cycle(s) (mid-1997 to late-1998) [11].

5.2 Post SM3A

As early as late-2000, there was evidence that the CCD sensitivity had declined at a rate of about 1% per year. Several modes declined as much as 2-3% per year [12]. Subsequent analyses over the entire STIS mission (mid-1997 to mid-2001) showed the wavelength-averaged rate of the CCD sensitivity loss was approximately 1% per year, with individual losses ranging from 0% per year to 1.5% per year [13].

5.3 Post SM3B

There is currently no published data for the change of the STIS CCD sensitivity since the last servicing mission, STS-109, in February 2002. However, the absolute flux calibration of the STIS MAMA imaging modes has been performed through comparing the observed and predicted count rates [14]. These

modes clearly show a time dependent sensitivity loss that is consistent with data previously reported [13]. Thus it was concluded that the wavelength-averaged sensitivity loss has remained at approximately 1% per year [14]. This data indicates that over the STIS 5-year mission the CCD sensitivity had declined approximately 5%.

6. DISCUSSION

The on-orbit data indicates that the contamination levels within the STIS instrument are low and most likely, are due to monolayer contamination depositions. The data also indicates that sensitivity loss has remained consistent over the STIS mission (1997 to present) also indicating that the contamination levels within the HST aft shroud are low. The requirements that were set for the instrument have been met, to-date, and if the rate remains constant, this will afford the STIS the capability to continue its science operations for several more years.

The on-orbit data is also a very strong indication that the extensive component outgassing processing was measurably effective and produced an instrument which has extremely low self-contamination. Although the outgassing processing was most likely the single most important aspect of the contamination control program, one cannot discount the extensive contamination control program which monitored the UV throughput of the optics throughout the instrument build, integration, and test activities (the greatest contamination risk to the telescope). Contamination modeling was also very important in influencing the on-orbit operations of the instrument. The modeling results aided substantially in convincing the Project Management that the shutter would need to be closed more often than originally planned, due to the potential for contamination and resulting performance degradation. The risk of a shutter failure was compared with the risk of performance degradation, and it was judged that the contamination risks were more compelling. Flight performance data now shows that closing the shutter and avoiding the viewing of bright objects has helped to maintain STIS's UV performance.

The contamination controls implemented for the Orbiter, Astronauts, and mission activities have been shown to be successful at not significantly increasing the telescope contamination levels. This is evidenced by the STIS sensitivity loss continuing to not increase after two additional servicing missions. The post-servicing mission bright object avoidance, developed for the post-SM2 HST on-orbit checkout and early

operations, has been shown to be significant as the STIS contamination critical surfaces (optics) were not exposed to bright objects while the contamination levels within the HST were at its highest levels (due to new installations).

7. SUMMARY

The STIS contamination control program while extensive and all encompassing produced an instrument whose self-contamination levels are extremely low (approximately 5% average CCD sensitivity loss to-date). The original five-year mission life can and has been extended due to the low outgassing characteristics of the instrument. To-date STIS has not exceeded its end-of-life requirement of 9% optical reflectance loss per optical element. The STIS contamination control program included a significant number of outgassing tests, aggressive cleaning techniques, and aggressive personnel training and monitoring, which have successfully produced an instrument whose self-contamination levels were below the requirement at the end of its original mission life (5 years on-orbit), and continues to provide magnificent technical data to the scientific community.

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